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CONTAINMENT LEAK SEARCH DURING BRUCE NGS 'B' 1988 STATION OUTAGE

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ABSTRACT

To minimize radionuclide dispersion at nuclear generating stations the containment volume is maintained at negative pressure and the containment boundary is periodically pressurized while 'off-power' to test for leakage. During the 1988 pressure test at Bruce NGS 'B' a leak search of this boundary was conducted concurrently to identify and quantify leakage. Ethylene tracer gas at 2.5% was injected into containment to achieve a concentration of approximately 30 $\mu\text{L/L}$ at the peak LOCA pressure of 88 kPag. Over 570 samples of station air were collected and analyzed for evidence of tracer gas. Out of eighteen areas found to have elevated tracer gas concentrations, only three were found to be leaking at over 1 kg/hr at 88 kPag and the sum of individual leakage from the discrete leakpaths found was considerably smaller than the measured leakage of 1094 kg/hr at 88 kPag. The majority of leakage was assumed to arise from general building leakage since tracer concentrations in the noncontaminated exhaust of Units 5 and 6 accounted for approximately 50% of the total measured leakage and since no large discrete leaks were found. This agrees with the laminar leakrate versus pressure relationship reported elsewhere.

job	file	date	report no.
32-157-553	835.6212	August 17, 1989	89-1-K



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EXECUTIVE SUMMARY

CONTAINMENT LEAK SEARCH DURING
BRUCE NGS 'B' 1988 STATION OUTAGE

T.G. Pringle

A physical containment barrier minimizes the potential release of radionuclides from nuclear plants. Periodic tests are required by the AECB to demonstrate the integrity of the containment boundary at Ontario Hydro's nuclear generating stations (that the air leakage is less than 2% per hour of the contained mass at design pressure). As part of the 1988 outage at Bruce NGS 'B' a pressure test was conducted during which the entire containment volume (reactor vaults, fuelling machine duct and service areas) was pressurized to the peak LOCA pressure of 88 kPag and the leakage rate measured at various pressures. A search for leakage sites was conducted concurrently.

During a previous pressure test at Bruce NGS 'A' in 1987, a tracer gas leak search technique was tested while soap application was retained as the primary leak detection method. The successful use of tracer gas and the time- and labour-intensive nature of the soap technique resulted in the use of tracer gas as the primary method of leak detection during the Bruce NGS 'B' outage in 1988.

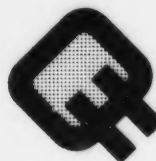
In the present study an ethylene tracer was injected into containment to achieve a concentration of approximately 30 $\mu\text{L/L}$. Subsequent analysis of station air revealed eighteen areas having elevated tracer gas levels including the vacuum building basement, the East Service Area, parts of Unit 0 and parts of Units 5 and 6. Although the tracer gas method easily detected many Type 1 and 2 leaks and a large Type 3 leak of 5.5 kg/hr, the existence of a second large Type 3 leak (10-30 kg/hr) was not deduced originally from tracer gas data. This was found to be due to the presence of a ventilation intake, located immediately downstream of the leak (Airlock 2, Unit 6), reducing tracer concentrations near the leak.

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The majority of station leakage was assumed to arise from general building leakage rather than from significant individual holes due to the existence of a relatively large amount of tracer in the noncontaminated exhaust stacks in Units 5 and 6, the fairly even distribution of tracer around each reactor vault, the apparent lack of several large discrete leaksites and the laminar nature of the pressure versus leakrate relationship reported by the leakrate measurement crew/9/.

Recommendations are proposed for future refinement of the tracer gas method.

RAY
D/E



ontario hydro research division

To: Mr. D. Pockett
Technical Manager
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CONTAINMENT LEAK SEARCH DURING BRUCE NGS 'B' 1988 STATION OUTAGE

T.G. Pringle

1.0 INTRODUCTION

The potential release of radionuclides from Ontario Hydro's multi-unit nuclear generating stations is minimized by a containment barrier which encompasses the reactors, the fuelling machine duct, the pressure relief manifold and both of the central and east service areas. The Atomic Energy Control Board requires periodic tests of this boundary to demonstrate both its integrity at design pressure and that air leakage is less than 2% of the contained volume (95,000 m³) per hour. Ontario Hydro has an inleakage specification of 1% of the contained volume per hour for Bruce NGS. During the first such pressure test at Bruce NGS 'B', performed in May of 1988, a concurrent leak search of the containment boundary was conducted.

The use of a tracer gas leak search technique has been studied previously/1,2/ and was successfully demonstrated with an ethylene tracer in May, 1987 at Bruce NGS 'A' during the first four-unit pressure test/3/. The traditional leak search technique, the application of soap solution around penetrations of the containment boundary, was also used at Bruce 'A' but proved both time- and labour-intensive while providing little useful information not provided by tracer gas. The soap solution method was found to be limited to suspected leaksites (eg. cracks and penetrations) and the range of useful quantification by this method was shown to be representative of insignificant leak rates (eg. 0.01 - 0.07 kg/hr)/3,4/. The tracer gas technique, on the other hand, was useful in detecting unsuspected leaks, required

less exposure time when leak searching in radiation fields, and could be used easily in relatively inaccessible areas. The leak search at Bruce 'B' relied on the tracer gas method to highlight areas of potential leakage with both subsequent localized ambient sampling and limited application of soap solution used to precisely locate leak sites (see Figure 1).

In order to determine the significance of particular leak sites to the overall leakage, and consequently whether repair is worthwhile, quantitative estimates of the leakage rate were obtained with a mass flowmeter "leak catcher" which has been described in detail elsewhere/5/.

2.0 EXPERIMENTAL DETAILS

Ethylene was used as a tracer because of its ease of detection and handling as well as because of a lack of toxic or corrosive decomposition products/3/. While ethylene is relatively well-absorbed by the molecular sieve used in the vault drier circuits at Ontario Hydro nuclear generating stations, tests performed during a previous study/3/ confirmed that ethylene would not accumulate to within flammable concentrations inside the vault vapour recovery systems.

The containment pressurization and tracer injection commenced at approximately 21:30 on May 22, 1988. Approximately 6100 litres of ethylene (as 2.7% v/v ethylene in nitrogen; lower explosive limit of ethylene - 3.1% v/v in air) were injected into containment during initial pressurization to 15 kPag. This corresponds to an estimated concentration of 56 $\mu\text{L/L}$ for the first leak search at 15 kPag and to approximately 34 $\mu\text{L/L}$ at the peak LOCA pressure of 88.7 kPag. Injection was accomplished via custom manifolds, outfitted with high-flow Victor regulators (3300 litres/min at 50 psig), installed on Units 5, 6, 0, 7 and 8. Injection into the instrument air lines used for pressurizing containment facilitated dilution of the tracer gas (Appendix 1). The distribution of tracer gas amongst the five inlets is given in Figure 1.

Sample collection for the first leak search at 15 kPag began at 23:15 on May 22 and was completed at approximately 01:30. Sample analysis was complete by 04:30. A second leak search at 88 kPag occurred between 09:45 on May 23 and ended at 13:15 during which time containment pressure went from 75 kPag through a maximum at peak LOCA pressure and subsequently dropped to 85 kPag. Time was not critical in the second search since the progress of the pressure test was not contingent on the conclusion of this search (see Appendix 2).

Ambient air samples were collected from locations throughout the station using battery-powered pumps and polyvinyl fluoride sample bags. Analysis was performed with two Photovac portable gas

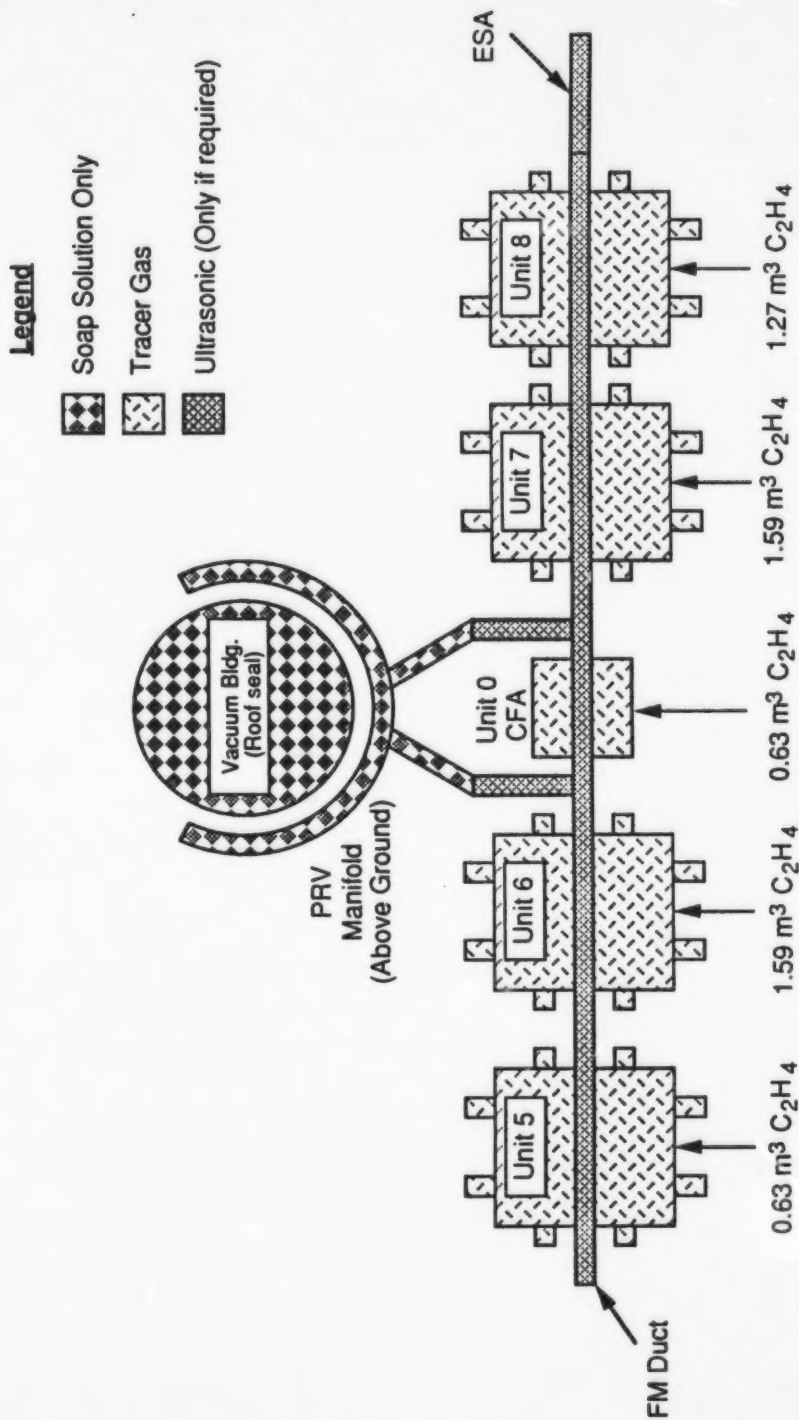


FIGURE 1

RECOMMENDED LEAK SEARCH METHODS AND TRACER GAS DISTRIBUTION

chromatographs equipped with photoionization detectors, located in a 'test' van situated on elevation 615' between Units 7 and 8. Details of the gas chromatographs and the analytical procedure can be obtained elsewhere (Appendix 4; /3/).

Of a total of 570 air samples which were collected from throughout the station, 250 samples were collected in each of the leak searches at 15 kPag and 88 kPag and an additional 70 samples were collected in various locations, and at various times. Where relatively high tracer gas concentrations warranted, further bag sampling and soap application was used to more accurately locate the leak.

3.0 RESULTS AND DISCUSSION

The sampling of containment, which was to be conducted using timer-operated pumps, encountered little success because of pump problems. However, an estimation of the tracer concentration in containment was obtained indirectly (Appendix 3) from measurements taken during venting from the contaminated-exhaust stack of Unit 0. The estimated containment concentration of 30 $\mu\text{L/L}$ was very close to the predicted concentration of 34 $\mu\text{L/L}$.

Leaks as determined by soap application were qualitatively classified as Type 1, 2 or 3 according to Lash and Braun/5/ but with the additional requirement that Type 3 leaks must represent strong airflow (>1 kg/hr). Type 2 leaks were reclassified to include those leaks which were formerly defined as Type 3 but which had weak flow. This classification was somewhat different than previously used at Bruce NGS 'A' where Type 3 leaks were defined as having severe foaming and audible hissing but could include relatively insignificant leaks as small as 0.01 kg/hr (ie. no strong airflow).

Out of 570 air samples collected, eighteen areas were considered to have rather high tracer gas concentrations and were subject to further scrutiny (see Table 1). In most cases further air sampling or soap spray application performed in the vicinity of relatively high tracer concentrations led to the discovery of one or more Type 1 or Type 2 leaks. Individual leakage rates in these cases were either unmeasurable by leak catcher (<0.01 kg/hr) or else were measured to be quite small. In some areas having elevated tracer concentrations (Entries 2, 3 in Table 1: confinement drier circuit) further leak searching was not conducted because the relatively low overall station leakrate made leak searching in these areas and the consequent dose uptake unnecessary.

In one case (AL2, RB6) a significant leak was not obvious from tracer gas levels but was easily found by manual inspection. This leak was measured at 9.5 ± 0.1 kg/hr (69 kPag) by leak

TABLE 1: AREAS OF HIGH TRACER CONCENTRATION

<u>No.</u>	<u>Location</u>	<u>Detection Method</u>	<u>Range of Tracer Concentration</u> <u>nL/L</u>	<u>Comments</u>
1	579' /RB5-RM013 near TC5	T	160	Type 1 leak in joint sealant, no follow-up; stagnant air; leak estimated at -0.1 kg/hr at 69 kPag)
2	579' /RB6 - Moderator rooms, confinement dryer circuit.	T	35 @ 15 kPag 476 @ 80 kPag	No action taken. Build-up in confinement dryer circuit. Separate circuit for each unit.
3	579' /591' RB8 - Moderator rooms	T	35 @ 15 kPag 476 @ 80 kPag	No action taken.
	579' /591' RB6 - Moderator rooms	T	58 @ 15 kPag 483 @ 80 kPag	No action taken.
4	591/Unit 0 - south side FMD SH/SJ9.5	T	30 - 640	Extra bag samples taken. Leak crew identifies 1/2" bolt missing in cable penetration (EP 41129) (5.5 kg/hr). Numerous Type 1 leaks and Type 2 leaking plugs (EP41114, 41128).
5	579' /Unit 0 - near AL15	O/T	7 - 450	Tracer detected on 579' and above on 615'. Joint seal bulging, Type 2 leak in cable penetration EP41735. Leakage measured at total of 1.2 kg/hr @ 73 kPag.

TABLE 1: AREAS OF HIGH TRACER CONCENTRATION

No.	Location	Detection Method	Range of Tracer Concentration nL/L	Comments
6	East Service Area/AL18	T	11-40 (15kPag) 150-500(80 kPag) 450-1800 (48 kPag)	Analyzed with local bag samples, searched by Leak Tec soap. AL18 air horn and door seal with small leaks(SST 4.18). Larger ESA source not found.
7	579' / Unit 0	T	37-450	Leak crew identifies Type 1 leaks at EP41268/41283
8	591' / Unit 0 D ₂ O Cleanup Room	T	14 - 100	Extra local samples taken Type 1 and 2 leaks found in EP41130/41131 and joint seal leak in NE corner of room.
9	591' / RB6	T	3 - 173	Joint leak in wall at SA9.2 Type 1/2 found by leak crew.
10	Vacuum building basement	T	5 - 130	Follow up bag samples show many small leaks near AL20 (some leakage noted, SST 4.18) and expansion joints near VP15/16. Individual leak rate too small to measure (<0.001 kg/hr).

TABLE 1: AREAS OF HIGH TRACER CONCENTRATION

No.	Location	Detection	Range of Tracer	Comments
		Method	Concentration nL/L	
11	AL2/ Unit 6	O	5 - 25; upwind of leak	Air line plug missing on AL2 measured to be 9.5 kg/hr at 69 kPag and 7.9 kg/hr at 48 kPag. Heater and large ventilation intake beside airlock disturbing normal airflow pattern.
12	RB6 -rear of RB from 615' to 693, and non- contaminated stack.	T	Evidence of plume 16-80 nL/L; 48 nL/L in stack	Analysis performed after pressure test.
13	Unit 0 -Rm S233 (Maint- enance area test facility)	T	280	Type 2 leak found at EP 41239 and 41232. No further action taken.
14	Unit 0 -579'.	O/T	12-116	Several Type 2 leaks in concrete joint at column SC7.5.
15	Unit 6 -Reactivity Mechanisms Deck/ PHT pumps	T	7-170	Indication of S to N flow. Later samples inconclusive. Possible leakage from pre- heater bolts cooling lines or RM Deck.
16	Unit 5 -RMD/PHT pumps	T	15-70	
17	Unit 5 -Airlock 2	T	17-25	Small leak in air supply line. Too small -no leak catcher measurement.

TABLE 1: AREAS OF HIGH TRACER CONCENTRATION

<u>No.</u>	<u>Location</u>	<u>Detection Method</u>	<u>Range of Tracer Concentration</u>	<u>Comments</u>
18	632' /Unit O	T	43-280 nL/L	Leaks too small to measure found around penetrations in stairwell ST29.

LEGEND T - leak found using tracer gas technique
 O - leak found by other methods (eg. soap application, sound, manual inspection).
 SST - Safety System Test
 AL - airlock
 ST - stairway
 EP - embedded part
 VP - vacuum pipe

catcher. However, the flow from this leak was throttled during measurement by the smaller pipe size in the leak catcher. Thus 9.5 kg/hr is likely a low estimate. By comparison, plugging of the leak and subsequent mass change measurements produced an estimate of 50 ± 27 kg/hr/9/.

In another case a series of leaks in the vicinity of Airlock 15 were independently detected via tracer gas data interpretation and by manual inspection. Elevated concentrations of tracer were found in an air shaft up to two floors above the leak site. The major leaks at this location, a bulging and separated expansion joint seal and a Type 2 leak in cable penetration EP41735, were measured by leak catcher to be passing a total of 1.2 kg/hr at approximately 73 kPag. Airlock 15 had also been found to be leaking slightly from an earlier seal test (SST4.18, /6/). The tracer concentrations found at this site, a large room extending from elevations 579' to 615', are shown in Figure 2, (ii), b).

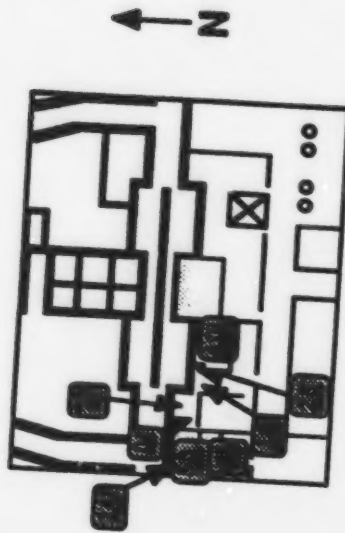
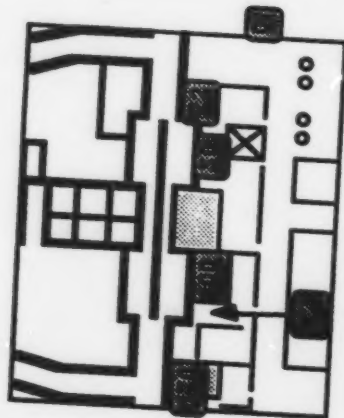
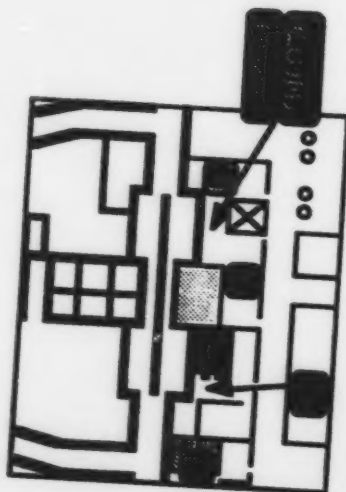
A third case (Entry 4 in Table 1) illustrates the utility of the tracer gas method for locating unexpected leaks. Elevated concentrations (30-640 nL/L) of tracer gas in Unit 0 on elevations 591' and 615' indicated a plume of tracer gas originating on elevation 591' in the vicinity of column SH9.5 (see Figure 2). Because of background noise, diligent searching and listening was required to locate the leak, a displaced bolt on electrical penetration EP 41129, which was subsequently measured at 5.5 kg/hr. Several other bolts on EP's 41114 and 41128 were also found to constitute Type 1 and 2 leaks.

Some sampling sites which exhibited relatively high tracer concentrations (East Service Area; transfer chamber TC5 in RB5; AL18) were probably not significant leak sites because of low air exchange rates. In the East Services Area (ESA) and at AL18, for example, tracer concentrations continued to increase after peak pressure. Thus tracer concentration by leakage from containment into the ESA, even at the reduced leakage rates resulting from lower containment pressure later in the test, was a more dominant process than tracer removal by air exchange also, further tracer sampling, inspection and soap application failed to identify any major leaks.

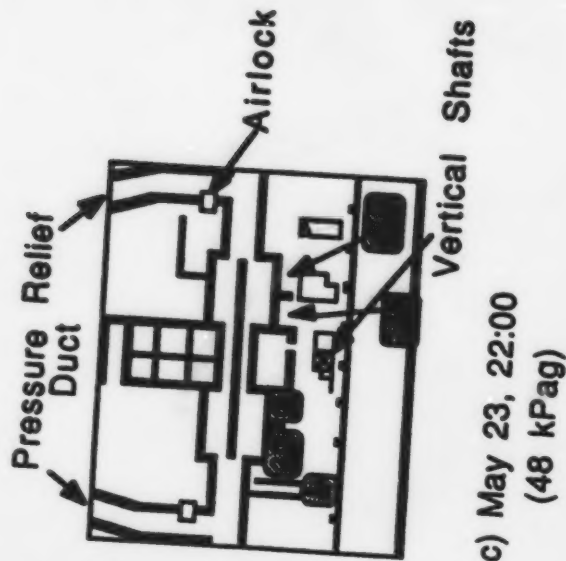
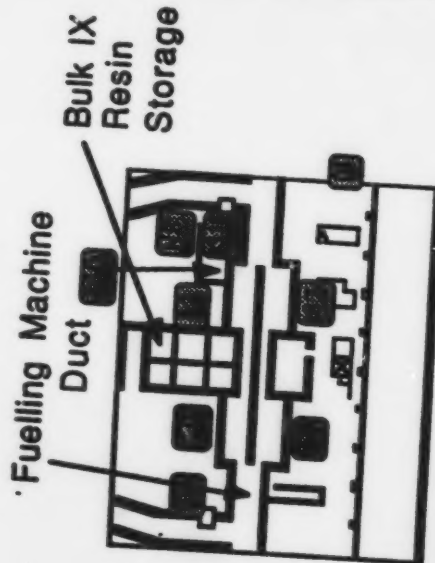
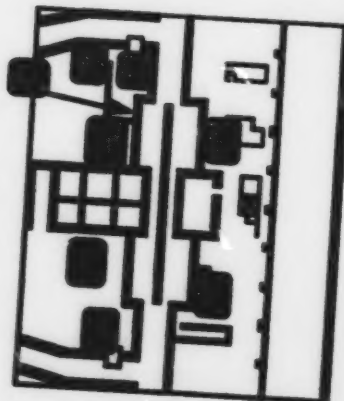
Moderator Rooms

Elevated concentrations of tracer gas (35-480 nL/L) were found to exist in one of the moderator rooms (Rm 104) in each of reactor buildings six and eight. In each reactor building this room is also connected, via a confinement drier, to rooms 004, 005, 017, 018, 105, 106 and 107. Neither the purge rate of the drier nor the total volume of this drier circuit can be estimated accurately and thus the leak rate cannot be determined. However, the leakage per reactor building would conservatively not be expected to exceed 5-10 kg/hr.

I) ELEVATION 591'



II) ELEVATION 579'



a) May 22, 22:00
(15 kPag)

b) May 23, 14:00
(88 kPag)

c) May 23, 22:00
(48 kPag)

FIGURE 2: TRACER CONCENTRATIONS IN UNIT 0, ELEVATIONS 579' AND 591'
(■) CONCENTRATION OF TRACER GAS IN nL/L

Upper Levels of Reactor Building Six

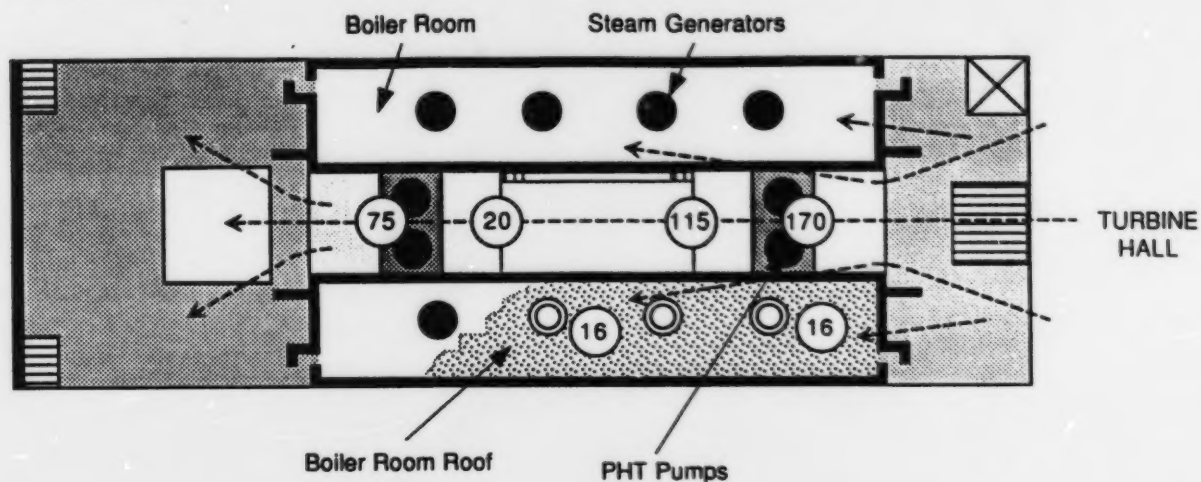
Despite many areas of elevated tracer gas concentrations, the associated Type 1 and 2 leaks and several Type 3 leaks, it is obvious that the total identified leakage amounts to considerably less than the measured leakage, 780 kg/hr at 69 kPag, for the whole of containment. Later analysis of data for RB6 provided evidence of a potentially significant leak. Figure 3 shows the concentration of tracer gas on elevation 678' and for a cross section of the north ventilation shaft on reactor six, respectively. At peak containment pressure, an average of 35 nL/L ethylene was found in the non-contaminated exhaust stack of unit 6. This was much higher than was found in Units 0, 5, 7 and 8 (<5, 16, 1, 3 nL/L respectively). The non-contaminated exhaust is one of two exhausts in the reactor auxiliary bay, the other being roof ventilation above the Zone 2/3 boundary at Column 12, and therefore should reflect atmosphere composition within the reactor auxiliary bay.

Samples taken from Column 14 (overlooking the turbine hall) show a tracer pattern similar to that of the exhaust with measurements for Units 5, 6, 7 and 8 being 25, 29, <1 and 2 nL/L respectively. Since the air at these sample locations comes from lower levels via the turbine hall/7/, evidence of containment leakage should be found there for Units 5 and 6. A previous report/8/ found air flowing primarily from south to north on elevations 663' and above, and north to south on elevations 615' to 639', although some flow from Column 12 southwards does exist between 663' and 693'. However, the only significant tracer concentrations were measured on 678' thus implicating this elevation as the source of the tracer gas on elevation 693'. Also, decreasing tracer concentrations in a south to north direction on Unit 6 at 678' indicates a local maximum concentration south of Column 9. A leak at this location could result in tracer gas being swept both across elevation 678' in a northerly direction as well as upwards and over the railing on elevation 693'. Penetrations in this area include preheater bolts, cooling water lines and PHT pump seals. Because the interpretation of the data occurred after the pressure test no confirmation of these conclusions has been obtained. It is interesting to note that the preheater bolts were the largest source of leakage found during commissioning tests of Unit 7/2/. However, since the leakage from the preheater bolt penetrations was estimated to be less than 3.6 kg/hr for Unit 7 during commissioning, it is not reasonable to assume that the preheater penetrations are solely responsible for the tracer gas in the noncontaminated exhaust.

Evaluation of Results

The collection and analysis of tracer samples could have been improved in two ways. The collection of samples could have been

a) ELEVATION 678'



b) CROSS-SECTION OF UNIT 6

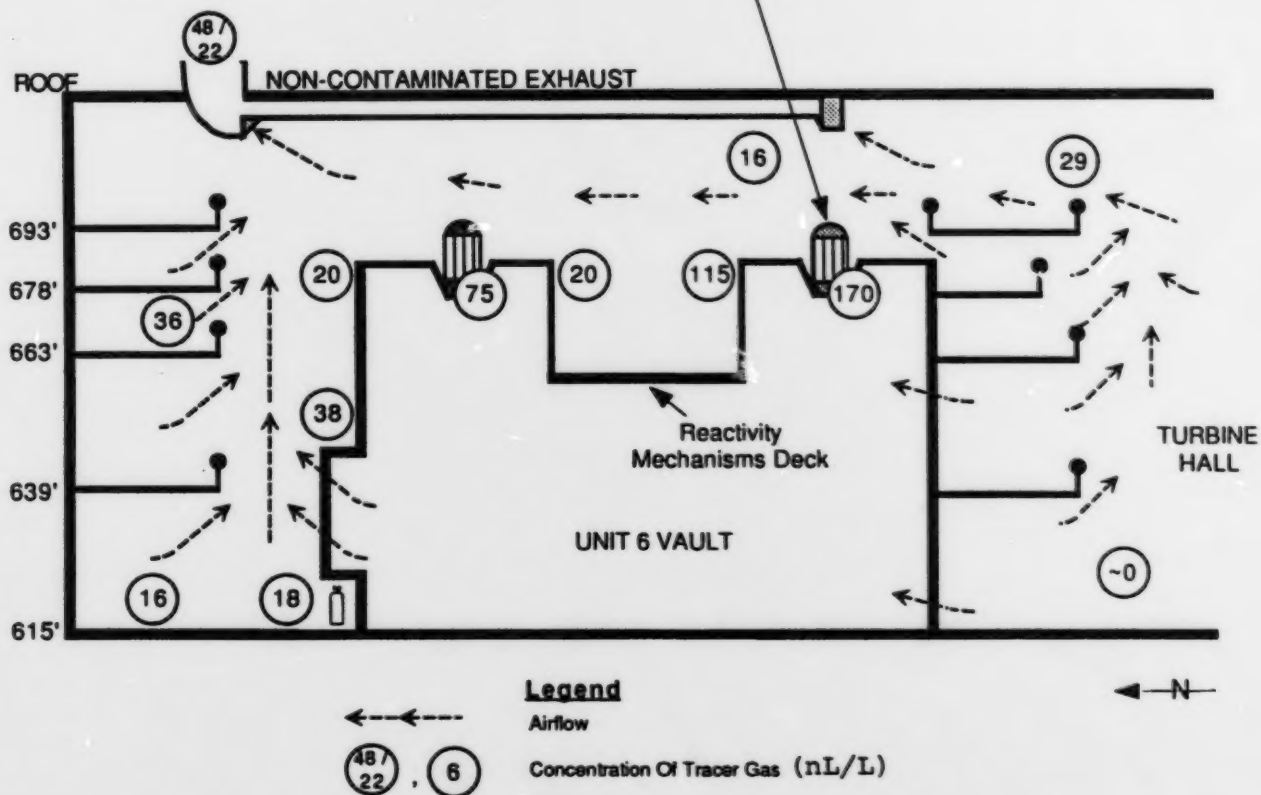


FIGURE 3

TRACER CONCENTRATION IN VICINITY OF BNGS UNIT 6
(14:00, May 23, 88kPag)

made simpler and faster through the use of more samplers. Also, there was a backlog in samples analysis caused by equipment problems with one of the gas chromatographs. While the dependence on one of the more sensitive Photovac GC/PID instruments was not as serious as dependence on a single GC/ECD as occurred at Bruce 'A' in 1987, acquisition of a third GC/PID instrument would be useful for backup.

The objective of the tracer gas leak search is the identification and location of leaks, especially significant ones, in the containment boundary. In the foregoing discussion eighteen areas of elevated tracer concentration were found including three significant leak sites totalling approximately 17 kg/hr at 65 kPag (approximately 20 kg/hr at 88 kPag). A potentially significant leak was suspected north of Unit 6 but not confirmed. Thus, although a number of leakpaths were found using this technique, the aggregate leakrate does not appear to equal a significant portion of the total measured leakage of 1094 kg/hr at 88 kPag/9/. However, this does not necessarily indicate the existence of an undiscovered leak. An examination of the leakrate versus pressure relationship reveals that containment leakage is predominantly laminar in nature. Furthermore, the leakage results are only 15-20% higher than leakage at commissioning which was also laminar. Thus it is likely that there are no major turbulent leakpaths but, instead, that the majority of the tracer measurements represent general leakage through the many tiny cracks expected to develop over time in and between components of such a large structure. It is probable that the elevated tracer concentrations found represent either minor leakage into areas of stagnant air (eg Vacuum Building basement, East Service Area) or moderate leakage from Type 3 leaks into areas of moving air (Airlock 2, EP41129, construction joint at Airlock 15, potentially PHT pump area in Figure 3). The average tracer concentration of 5-40 nL/L in the auxiliary bays therefore probably represents the aggregate of many small laminar leakpaths and possibly a few relatively small turbulent leaks. The higher tracer concentrations around and in the containment exhaust of Units 5 and 6 indicate that these units account for the bulk of this type of leakage in the station. The non-contaminated exhaust in these two units, with tracer concentrations of approximately 16 and 35 nL/L, respectively, alone would represent a total of approximately 550 kg/hr (eg. Unit 6: 35×10^{-6} (ethylene) $\times 85 \text{ m}^3/\text{s}$ (stack flow) equals approximately 440 kg/hr of containment air at 69 kPag (approximately 30 $\mu\text{L/L}$ ethylene) 600 kg/hr at 88 kPag). With total containment leakage measured to be 1094 kg/hr at 88 kPag, leakage from Units 5 and 6 could thus account for approximately 55% of total leakage in only 20% of the station exhaust airflow (roof ventilation and non-contaminated exhaust).

Of course, a precise measurement of tracer loss via the exhaust system can only be made if more extensive monitoring of the tracer concentrations, in the stacks and on containment is

performed. In general the foregoing data and analysis demonstrate the effective use of the tracer gas technique to survey the station for leakage. Subsequent use of local tracer sampling, soap application and manual inspection was then capable of locating leaks efficiently and in at least one case positively identified a significant leak in an unexpected location (5.5 kg/hr; Entry #4 in Table 1). However, it is important to note that the largest leak detected (Unit 6, Airlock 2) was one the existence of which could not be deduced easily from the available tracer gas data. In order to facilitate interpretation of tracer gas data it is essential that more detailed airflow information be obtained. The tracer gas approach practiced in 1988 and reported here was more effective, from both a labour and a time perspective (and therefore cost perspective) than the station-wide soap application practiced as the primary leak detection approach during the BNGS 'A' outage in 1987.

4.0 CONCLUSIONS

1. The tracer gas technique performed well as the primary leak search technique, detecting several Type 3 leaks and many Type 1 and 2 leaks.
2. Finding leaksites requires diligent searching due to ambient noise and complex systems. To attempt such detailed searching without the assistance of tracer gas to indicate regions of high leakage would be prohibitively expensive and time consuming.
3. Tracer gas data interpretation would benefit from better knowledge of airflow rate and direction within the station.
4. Additional sampling and analytical equipment would be beneficial to facilitate sample collection and analysis and provide a backup for machine failure.

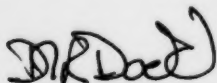
5.0 RECOMMENDATIONS

1. A detailed examination of station airflow rate and direction should be undertaken to identify locations where tracer may either built up due to stagnant conditions or disperse due to high ventilation rates.
2. All areas of elevated tracer concentration should be carefully assessed and where warranted, thoroughly searched - a hole of 1 cm diameter can represent turbulent flow of up to 95 kg/hr at peak containment pressure but can be easily missed in the station.
3. More extensive sampling of the exhaust stacks of all units and of containment should be considered in future tracer tests.

Acknowledgement

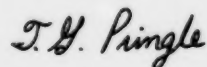
The efforts and skill of the Tracer Gas Leak Search crew (C. Breckenridge and D. Mueller, Materials Chemistry Section; C. Donovan, B. Handy and T. Jarv, Environmental Science Section) in preparing for and conducting the Tracer Gas Leak Search are gratefully acknowledged.

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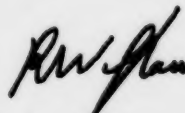
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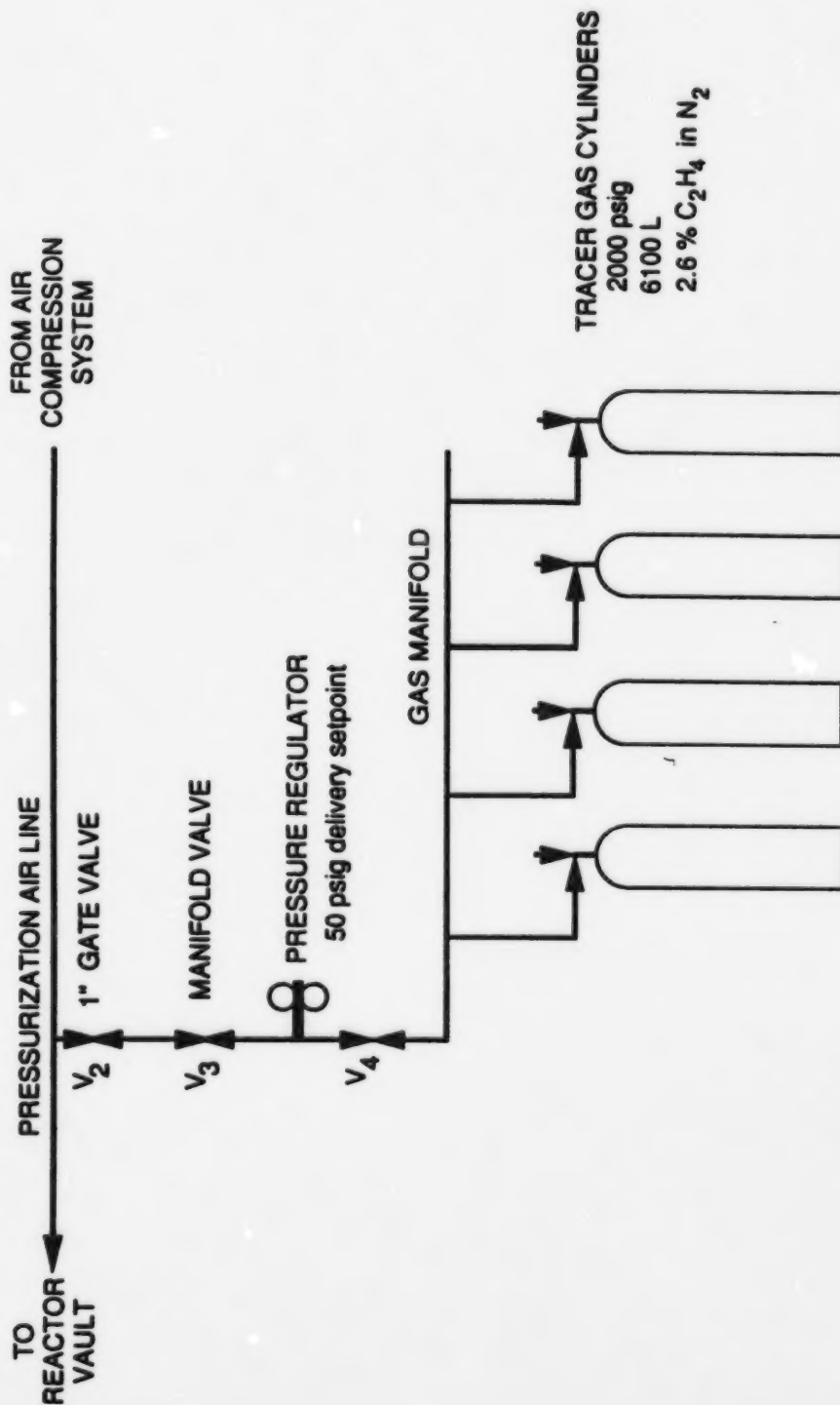


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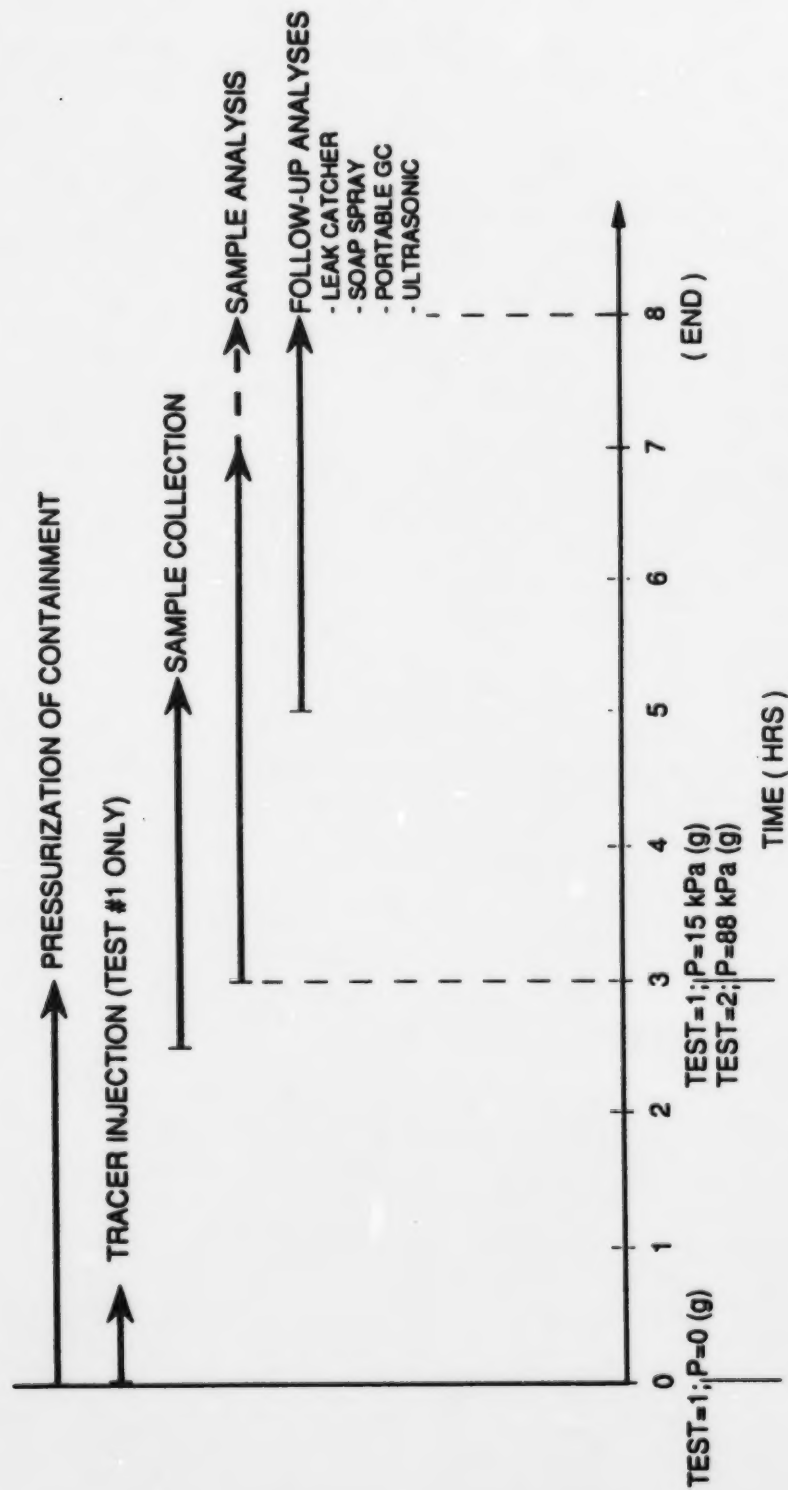
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APPENDIX 1

INJECTION SYSTEM FOR TRACER GAS.



APPENDIX 2

TRACER GAS LEAK SEARCH FLOWSHEET

APPENDIX 3

Tracer Gas Concentration in Containment

Six automatic timer-operated samplers were placed in containment, two each in Units 0, 5 and 8. Only three samplers operated and the results for these three indicated that there was a problem with the pumps. Instead, an approximate vault concentration was calculated from measurements taken from the contaminated exhaust during the test venting of containment via Unit 0.

A concentration of 1490 nL/L was recorded during the vent phase which lasted for 110 minutes at 14:40 on May 23 and resulted in a containment pressure drop from 188 kPa to 170 kPa. Thus approximately 16900 m³ of air was released from approximately 95000 m³ of contained volume in 110 minutes. A vault concentration of approximately 30 µL/L would be required, in this vent of 2.6 m³/s, to produce the observed concentration (1.5 µL/L) in the nominally 48 m³/s contaminated exhaust rate for Unit 0. This compares favourably with the 34 µL/L expected at 188 kPa.

APPENDIX 4

Details of Sample Collection and Analysis

Air samples were collected via small battery-powered (1.5 - 3.0 V) and switch-operated pumps attached to TEDLAR (Dupont) polyvinyl fluoride bags (3L). In each leak search, twelve (12) Bruce Operations personnel collected approximately 250 samples, divided into 44 trips of about five samples each (see Table 4.1). The bags were sealed mechanically with butterfly clamps and returned to the field laboratory on elevation 615' for analysis.

Samplers connected to electronic timers and protected from contamination by plastic bags were placed in containment. Unfortunately these samplers did not operate properly since the pumps had been derated via the addition of load resistors and the battery voltage was not high enough for consistent operation.

Gas sample analysis was performed using two Photovac portable gas chromatographs (GC) equipped with photoionization detectors: a Model 10S30 attached to a Varian 4790 integrator and a Model 10S50.

The carrier gas was ultra-high purity dry air passed through a purification train, consisting of charcoal traps, at a flowrate of 50 mL/min. All tubing was PTFE or stainless steel. The sample injection volume was 1 mL and the detection limit for ethylene was approximately 2 nL/L.

The adsorption of ethylene on TEDLAR is minimal so sample bags were reused after repeated cycles of filling with clean air and evacuation by vacuum pump.

Table 4.1: Location of Gas Samples

Note: North refers to construction north.

Trip Sample Unit Access

#	#	#	Elev.	Location
1	1	ESA	591	Rm ES113 in front of AL18.
	2			Rm ES116, on railing (door kickpad labelled ES041b).
	3			Rm ES105 vestibule in front of airlock AL17.
	4			Rm ES041, on platform railing, east end of room (door kickpad labelled ES116).
	5			Rm ES041 under platform, east end of room.
	6			Rm ES201 northwest corner.
	7	8	579	Near 8N10 east of Unit 8.
2	1	0		Rm S002, sample on south edge of railing near SC9.5.
	2	0		Rm S004, sample on south edge of railing near SH9.5.
3	1	0	579	Sample at SC7.
	2	0		10' east of SA7.
	3	0		Railing of stairway ST48.
	4	0		Top of first flight of stairway ST14.
	5	0		Between SK6 and SK7, 12' from PRD wall.
	6	0		Centre of RM S018, 12' from AL15.
4	1	5	591	Rm 104.
	2	5		Rm 112.
	3	6		Rm 104.
	4	6		Rm 112.
	5	7		Rm 104.
	6	7		Rm 112.
	7	8		Rm 104.
	8	8		Rm 112.
5	1	5	591	Between SC9 and SC10.
	2	5		SN10.
	3	6		6B10.
	4	6		6N10.
	5	6		East of unit 6, railing of stairs to uppermost platform near 8P9.5.
	6	5	579	Between SB9 and SB8, 15' from AL11.
6	1	0	591	South railing edge at SH9.5.
	2	0		Midway between SJ9.5 and Rm S147.
	3	7		Near 7B10.
	4	7		Near 7N10.
	5	8		8B10.
	6	8		8N10.

Table 4.1 (cont'd)

2

	7	B		East of unit 8, railing of stairway to uppermost platform near 8P9.5.
7	1	VB	615	EFADS building in east passageway, 10' from PR manifold wall.
	2	VB		EFADS building in west passageway, 10' from PR manifold wall.
	3	VB		EFADS building, north filter room.
8	1	VB	615	Top of stairs ST21, east side of AL20.
	2			Top of stairs ST22, respirator rack at TC6.
	3			Between vacuum pipes VP16 and VP15.
	4			Between vacuum pipes VP3 and VP4.
	5			Halfway along corridor S016, leading to VB.
9	1	5	615	12' from west vault wall between C9 and C9.4.
	2	5		Annulus gas area, south wall of reactor between G11 and H11, use steel ladder.
	3	5		Inside Rm 202 Mezzanine.
	4	5		12' from east vault wall on roof of Rm 210 between M9 and M10.
	5	5		12' from east vault wall between M8 and M9.
	6	5		In doorway at SN7.5
	7	5		SCB.
	8	5		Midway between stairs ST10 and charcoal filter room.
10	1	5	615	Down ST1 to 579', inside Rm 012, or on gate of AL6.
	2	5		Up ST1 to 615, in Rm 224.
	3	5		Under Rm 224, beside gas cylinders.
	4	5		Inside Rm 305.
	5	5		Near instrument air compressor between SE6 and SG6.
	6	5		Down ST2 to 579', inside RM013.
	7	5		NE corner of charcoal filter room.
	8	5	591	Rm 118, secondary control room, partway down stairs from 591'.
11	1	6	615	12' from west vault wall between C9 and C9.4.
	2	6		Annulus gas area, south wall of reactor between G11 and H11, use steel ladder.
	3	6		Rm 202 Mezzanine.
	4	6		12' from east vault wall on roof of Rm 210 between M9 and M10.
	5	6		12' from east vault wall between M8 and M9.
	6	6		In doorway at SN7.5
	7	6		SCB.
	8	6		Midway between stairs ST10 and charcoal filter room.
12	1	6	615	Down ST1 to 579', inside Rm 012, or on gate of AL6.
	2	6		Up ST1 to 615, in Rm 224.
	3	6		Under Rm 224, beside gas cylinders.
	4	6		Inside Rm 305.
	5	6		Near instrument air compressor between SE6 and SG6.
	6	6		Down ST2 to 579', inside RM013.
	7	6		NE corner of charcoal filter room.
	8	6	591	Rm 118, secondary control room, partway down stairs from 591'.
13	1	7	615	12' from west vault wall between C9 and C9.4.

Table 4.1 (cont'd)

3

	2	7		Annulus gas area, south wall of reactor between G11 and H11, use steel ladder.
	3	7		Rm 202 Mezzanine.
	4	7		12' from east vault wall on roof of Rm 210 between M9 and M10.
	5	7		12' from east vault wall between M8 and M9.
	6	7		In doorway at SN7.5
	7	7		SC8.
	8	7		Midway between stairs ST10 and charcoal filter room.
14	1	7	615	Down ST1 to 579', inside Rm 012, or on gate of AL6.
	2	7		Up ST1 to 615, in Rm 224.
	3	7		Under Rm 224, beside gas cylinders.
	4	7		Inside Rm 305.
	5	7		Near instrument air compressor between SE6 and SG6.
	6	7		Down ST2 to 579', inside RMD13.
	7	7		NE corner of charcoal filter room.
	8	7	591	Rm 118, secondary control room, partway down stairs from 591'.
15	1	8	615	12' from west vault wall between C9 and C9.4.
	2	8		Annulus gas area, south wall of reactor between G11 and H11, use steel ladder.
	3	8		Rm 202 Mezzanine.
	4	8		12' from east vault wall on roof of Rm 210 between M9 and M10.
	5	8		12' from east vault wall between M8 and M9.
	6	8		In doorway at SN7.5
	7	8		SC8.
	8	8		Midway between stairs ST10 and charcoal filter room.
16	1	8	615	Down ST1 to 579', inside Rm 012, or on gate of AL6.
	2	8		Up ST1 to 615, in Rm 224.
	3	8		Under Rm 224, beside gas cylinders.
	4	8		Inside Rm 305.
	5	8		Near instrument air compressor between SE6 and SG6.
	6	8		Down ST2 to 579', inside RMD13.
	7	8		NE corner of charcoal filter room.
	8	8	591	Rm 118, secondary control room, partway down stairs from 591'.
17	1	0	615	Hang sample over edge of floor in air shaft in Northeast corner of Rm 215.
	2	0		Transfer chamber equalization port between ST14 and wall of TC2.
	3	0		Transfer chamber equalization port behind column SJ9.5.
	4	0		Inside Rm S255.
	5	0		Transfer chamber equalization port behind column SB7.5.
	6	0		Rm 213, 12' in front of column between two transfer chamber doors.
	7	0		Rm 215, 12' in front of column between two transfer chamber doors.
18	1	0	615	Top of stairway ST29, elevation 632'.
	2	0		Inside Rm S246, outside north wall of spent fuel transfer bay.
	3	0		North end of west side of port area S252, on railing.
	4	0		South end of east side of port area S252, on railing.
	<u>Note:</u> Look for bubbles in spent fuel storage pool from underwater penetrations.			

Table 4.1 (cont'd)

4

19	1,2	0	615	Go down stairs ST37 to ECI pump room Rm030, one sample each at either end of the hole in the floor grating on elevation 551'.
	3	0		Rm R7-117, elevation 586, midway along hole in floor on west side of room.
20	1	5	639	Inside Rm 312.
	2	5		On roof of Rm312, 12' from reactor vault wall.
	3	5		12' from vault wall between C7 and C8; if reactor has 'up/up' take sample on top, approx. 4' from penetration on wall.
	4	5		Above roof of Rm 224, attach to grating elevation 654'.
	5	5		Inside Rm 310.
	6	5		On outside edge of roof AL4.
	7	5		Up stairs ST2 to 663', sample on south railing of air shaft between Col. G and H.
21	1	5	639	Inside Rm 311.
	2	5		On roof of instrument room Rm 311.
	3	5		Sample on top of cement shielding wall near Col M10 on east vault wall.
	4	5		Inside Rm 302.
	5	5		Col. G11 platform gas chromatograph, south vault wall.
	6	5		12' from south vault wall midway near Col E11 in Rm 303.
22	1	6	639	Inside Rm 312.
	2	6		On roof of Rm312, 12' from reactor vault wall.
	3	6		12' from vault wall between C7 and C8; if reactor has 'up/up' take sample on top, approx. 4' from penetration on wall.
	4	6		Above roof of Rm 224, attach to grating elevation 654'.
	5	6		Inside Rm 310.
	6	6		On outside edge of roof AL4.
	7	6		Up stairs ST2 to 663', sample on south railing of air shaft between Col. G and H.
23	1	6	639	Inside Rm 311.
	2	6		On roof of instrument room Rm 311.
	3	6		Sample on top of cement shielding wall near Col M10 on east vault wall.
	4	6		Inside Rm 302.
	5	6		Col. G11 platform gas chromatograph, south vault wall.
	6	6		12' from south vault wall midway near Col E11 in Rm 303.
24	1	7	639	Inside Rm 312.
	2	7		On roof of Rm312, 12' from reactor vault wall.
	3	7		12' from vault wall between C7 and C8; if reactor has 'up/up' take sample on top, approx. 4' from penetration on wall.
	4	7		Above roof of Rm 224, attach to grating elevation 654'.
	5	7		Inside Rm 310.
	6	7		On outside edge of roof AL4.
	7	7		Up stairs ST2 to 663', sample on south railing of air shaft between Col. G and H.
25	1	7	639	Inside Rm 311.
	2	7		On roof of instrument room Rm 311.
	3	7		Sample on top of cement shielding wall near Col M10 on east vault wall.
	4	7		Inside Rm 302.

Table 4.1 (cont'd)

5

5	7		Col. GII platform gas chromatograph, south vault wall.
6	7		12' from south vault wall midway near Col EII in Rm 303.
26	1	8	639 Inside Rm 312.
	2	8	On roof of Rm312, 12' from reactor vault wall.
	3	8	12' from vault wall between C7 and C8; if reactor has 'up/up' take sample on top, approx. 4' from penetration on wall.
	4	8	Above roof of Rm 224, attach to grating elevation 654'.
	5	8	Inside Rm 310.
	6	8	On outside edge of roof AL4.
	7	8	Up stairs ST2 to 663', sample on south railing of air shaft between Col. G and H.
27	1	8	639 Inside Rm 311.
	2	8	On roof of instrument room Rm 311.
	3	8	Sample on top of cement shielding wall near Col M10 on east vault wall.
	4	8	Inside Rm 302.
	5	8	Col. GII platform gas chromatograph, south vault wall.
	6	8	12' from south vault wall midway near Col EII in Rm 303.
28	1	0	639 In center of Rm 310, new fuel handling.
	2	0	South edge of roof of concrete roof of the transfer chambers, Col SC9.5.
	3	0	Aisle between grey metal breaker panels and west wall of transfer chamber roof in Rm s308, midway between penetrations in wall.
	4	0	Between north wall of east transfer chambers and CFA vapour recovery system.
	5	0	North edge of concrete roof of east transfer chambers.
	6	0	Aisle between grey metal breaker panels and east wall of transfer chamber roof in Rm s313 (ventilation equipment room), midway between penetrations in wall.
	7	0	Between south wall of transfer chamber and CFA vapour recovery system, Col SH9.5.
29	1,2	5	678 Boiler room west, one sample each on walkways at E8 and E9, sample middle of walk
	3,4	5	Boiler room east, one sample each on walkways at E8 and E9, sample middle of walk
	5	5	North service area, middle of north railing over air shaft between G6 and H7.
30	1	5	On floor between PHT pumps on north side of reactivity deck.
	2	5	Hang sampler over railing at north side of reactivity mechanisms deck.
	3	5	Hand sampler over railing at south side of reactivity mechanisms deck.
	4	5	On floor between PHT pumps on south side of reactivity mechanisms deck.
31	1,2	6	678 Boiler room west, one sample each on walkways at E8 and E9, sample middle of walk
	3,4	6	Boiler room east, one sample each on walkways at E8 and E9, sample middle of walk
	5	6	North service area, middle of north railing over air shaft between G6 and H7.
32	1	6	On floor between PHT pumps on north side of reactivity deck.
	2	6	Hang sampler over railing at north side of reactivity mechanisms deck.
	3	6	Hand sampler over railing at south side of reactivity mechanisms deck.
	4	6	On floor between PHT pumps on south side of reactivity mechanisms deck.
33	1,2	7	678 Boiler room west, one sample each on walkways at E8 and E9, sample middle of walk
	3,4	7	Boiler room east, one sample each on walkways at E8 and E9, sample middle of walk

Table 4.1 (cont'd)

6

	5	7		North service area, middle of north railing over air shaft between G6 and H7.
34	1	7		On floor between PHT pumps on north side of reactivity deck.
	2	7		Hang sampler over railing at north side of reactivity mechanisms deck.
	3	7		Hand sampler over railing at south side of reactivity mechanisms deck.
	4	7		On floor between PHT pumps on south side of reactivity mechanisms deck.
35	1,2	8	678	Boiler room west, one sample each on walkways at E8 and E9, sample middle of walk
	3,4	8		Boiler room east, one sample each on walkways at E8 and E9, sample middle of walk
	5	8		North service area, middle of north railing over air shaft between G6 and H7.
36	1	8		On floor between PHT pumps on north side of reactivity deck.
	2	8		Hang sampler over railing at north side of reactivity mechanisms deck.
	3	8		Hand sampler over railing at south side of reactivity mechanisms deck.
	4	8		On floor between PHT pumps on south side of reactivity mechanisms deck.
37	1	5	693	On the roof of Boiler Rm West, 4' above roof on northern-most steam generator.
	2	5		On the roof of Boiler Rm west, 4' above roof on southern-most steam generator.
	3	5		On the roof of Boiler Rm East, 4' above roof on northern-most steam generator.
	4	5		On the roof of Boiler Rm East, 4' above roof on southern-most steam generator.
	5	5		Railing at 5H14.
	6	5		Non-contaminated exhaust, sample from pressurized end of plastic tube at coldfinger.
38	1	6	693	On the roof of Boiler Rm West, 4' above roof on northern-most steam generator.
	2	6		On the roof of Boiler Rm west, 4' above roof on southern-most steam generator.
	3	6		On the roof of Boiler Rm East, 4' above roof on northern-most steam generator.
	4	6		On the roof of Boiler Rm East, 4' above roof on southern-most steam generator.
	5	6		Railing at 6H14.
	6	6		Non-contaminated exhaust, sample from pressurized end of plastic tube at coldfinger.
39	1	7	693	On the roof of Boiler Rm West, 4' above roof on northern-most steam generator.
	2	7		On the roof of Boiler Rm west, 4' above roof on southern-most steam generator.
	3	7		On the roof of Boiler Rm East, 4' above roof on northern-most steam generator.
	4	7		On the roof of Boiler Rm East, 4' above roof on southern-most steam generator.
	5	7		Railing at 7H14.
	6	7		Non-contaminated exhaust, sample from pressurized end of plastic tube at coldfinger.
40	1	8	693	On the roof of Boiler Rm West, 4' above roof on northern-most steam generator.
	2	8		On the roof of Boiler Rm west, 4' above roof on southern-most steam generator.
	3	8		On the roof of Boiler Rm East, 4' above roof on northern-most steam generator.
	4	8		On the roof of Boiler Rm East, 4' above roof on southern-most steam generator.
	5	8		Railing at 8H14.
	6	8		Non-contaminated exhaust, sample from pressurized end of plastic tube at coldfinger.
41	1	0	693	Contaminated exhaust, sample from pressurized end of plastic tube at cold finger.
	2	0		Non-contaminated exhaust, sample from pressurized end of plastic tube.
	3	5		Contaminated exhaust, sample from pressurized end of plastic tube at cold finger.
	4	6		Contaminated exhaust, sample from pressurized end of plastic tube at cold finger.
	5	7		Contaminated exhaust, sample from pressurized end of plastic tube at cold finger.

Table 4.1 (cont'd)

7

6	0		Contaminated exhaust, sample from pressurized end of plastic tube at cold finger.
42	1	0	591 15' from wall of fuelling machine duct at SB9.5.
	2	0	East edge of railing at SC9.5.
	3	0	615 Transfer chamber equalization port in room S-260, behind low retaining wall, North side of room.

The following two trips to be made only if authorized by Research Leak Search crew.

43	1	0	693 Contaminated exhaust, sample from pressurized end of plastic tube at cold finger.
	2	0	Non-contaminated exhaust, sample from pressurized end of plastic tube at cold finger
	3	5	Contaminated exhaust, sample from pressurized end of plastic tube at cold finger.
	4	6	Contaminated exhaust, sample from pressurized end of plastic tube at cold finger.
	5	7	Contaminated exhaust, sample from pressurized end of plastic tube at cold finger.
	6	8	Contaminated exhaust, sample from pressurized end of plastic tube at cold finger.
44	1	5	693 Non-contaminated exhaust, sample from pressurized end of plastic tube at cold finger
	2	6	Non-contaminated exhaust, sample from pressurized end of plastic tube at cold finger
	3	7	Non-contaminated exhaust, sample from pressurized end of plastic tube at cold finger
	4	8	Non-contaminated exhaust, sample from pressurized end of plastic tube at cold finger